



United Stirling's Solar Engine Development — the background for the Vanguard Engine

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Abstract

The Vanguard project engine, named 4-95 Mk II Solar Stirling Engine, represents the result from four years of solar engine development at United Stirling. In these development activities United Stirling has participated in programs on contracts from JPL and DOE, the latest being the Vanguard project. A major part of the development has also been internally funded.

The development started in 1979 based on the then existing 4-95 laboratory test engine which thru the 4 years has been converted to a solar version and significantly improved in several areas. The conclusion of the Vanguard project results in a new engine generation of a design that can be regarded as a preproduction prototype.

The major part of the solar engine development has been concentrated to the three different areas, the receiver, the lubrication system and the control system, but improvements have been made on most components. The new components were first tested on engines in United Stirling's laboratory in Malmö. Five such engines are on test within the solar project. Thereafter the function of the components has been validated in actual solar tests. These tests started at Georgia Institute of Technology in 1981 and have then from the beginning of 1982 been performed at JPL's test station at Edwards Air Force Base.

This paper describes the development and testing resulting in the Vanguard engine and some of the characteristics of the Stirling engine based power conversion unit.

Introduction

United Stirling is a company within the industrial corporation FFV. The company's task is to develop the Stirling engine for commercial applications.

The development work has been going on since 1969 resulting in engines in different sizes of our own designs. The present engine family is shown in figure 1. United Stirling is now concentrating the efforts on four different application projects. One is the Automotive Stirling project with the ASE engine, a second one is the Submarine project mainly concentrating on a 4-275 engine, a third is the Auxiliary Power Unit project with the V160 engine and the fourth is the Solar project with the 4-95 Solar engine, the subject for this presentation.

ENGINES	
4-95	40 kW
4-275	75 kW
ASE	55 kW
V-160	12 kW

Fig 1. United Stirlings engine family



Solar development programs

Although it of course has always been an awareness at United Stirling of the possibility to use the Stirling engine for solar energy conversion our activities in the field were very low until 1978. We then became participants in a NASA-funded study together with MTI. This study identified both the kinematic and the free-piston Stirling engine as viable candidates for the solar application. The next year, 1979, we accepted participation in a JPL-program. Our task was to redesign the drive unit to fit to and be able to operate in the EAFB test bed concentrator and to deliver one drive unit while JPL developed the receiver. Participation in this program rose our interest in receiver design and we decided in 1980 to develop a receiver design of our own. This was a natural step since in the Stirling engine the receiver is an integral part of the engine and our intention was to be capable to deliver a complete Stirling engine for an application in which the commercialization of the engine could be realized. From 1980 and on our own extensive solar engine development program has been going on. In addition to that, and as one of the significant components of our solar engine development we 1982 became members of the Vanguard program which now is being realized in hardware in Palm Springs through delivery of the concentrator from Advanco and the PCU from United Stirling. The Stirling engine in the Vanguard project is the first engine in the new generation internally at United Stirling called the 4-95 Mk II Solar SE. This engine is of course a product of the Vanguard project, but in reality the result of a much broader development program at United Stirling. This development program is the combination of the Vanguard project and internally funded solar engine development. A summary of the externally funded solar development programs in which we have participated is given in figure 2.

USAB SOLAR ACTIVITIES

• NASA STUDY 1978 – 1979

15 KW SOLAR STIRLING ENGINE

• JPL PROJECT 1979 – 1981

INSTALLATION OF THE FIRST SOLAR STIRLING ENGINE WITH HYBRID RECEIVER IN A PARABOLIC DISH

• DOE PROJECT 1982 –

TEAM MEMBER OF THE VANGUARD PROJECT

Fig 2. Solar programs

The engine choice for solar applications: 4-95

The development of the Solar Stirling engine has during the last 3-4 years been concentrated to the 4-95 engine, figure 3. The reasons for choosing this engine were several. The engine size fits to a concentrator within the size range, 10-18 m diameter, that seems to be most cost effective. The existing JPL test bed concentrator and the 4-95 engine are almost perfect in sizes for each other which means that an opportunity to perform realistic hardware tests existed. The 4-95 engine was one of United Stirling's engines, that had the highest amount of accumulated running hours with rather good results. Figure 4 shows a summary of the present experience with the 4-95 engine.

The 4-95 engine was originally designed as a laboratory test engine in 1975. It has since then been used as the baseline engine in the beginning of the Automotive Stirling Engine program and as the first underwater engine designed by United Stirling. The further developed 4-95 engine is now chosen as the solar Stirling engine.

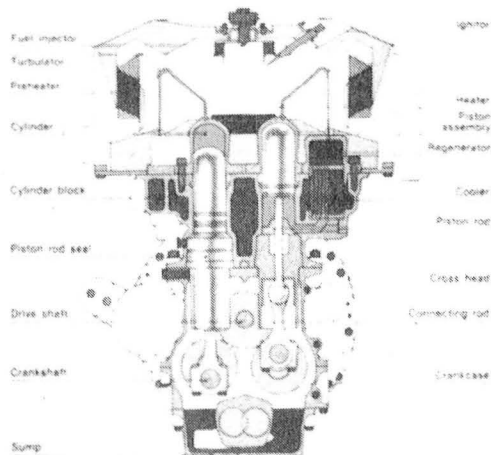


Fig 3. 4-95 cross section

4-95 ENGINE STATUS		Nov 1983
● Number of engines built		27
● Running hours		
● in total		41000
● single engine		11000

Fig 4. 4-95 Status

Main areas of redesign

Although the 4-95 engine in many respects was suitable as a solar energy converter there was also a need to redesign and further develop the engine in a number of areas. The engine must be able to operate in all different orientations from horizontal to upside down when following the movement of the concentrator. In the Advanco concentrator with its gimble mechanism it also rotates around its vertical axis. This means that it was necessary to completely redesign the lubrication system. The original heater was strictly designed as a heat ex-

changer for convective heat transfer from combustion gases. It was therefore necessary to develop a new heater suitable as a radiative heat exchanger together with a cavity surrounding it and thus fit the engine with a solar receiver. The receiver of a Stirling engine, in contrast to other engines, is an integral engine component. The control systems of the 4-95 engine were designed for applications with other and more complex control functions and with stronger requirements on response times than needed for the solar application. This was the case for both the pressure (power) control system and the electronic control system. Therefore new control systems had to be developed. Also in order to design an autonomous power conversion unit to be placed up in the focal mount a new radiator system had to be developed.

The major development work has been concentrated to the mentioned four areas, but significant changes have also been introduced on a large number of the engine components. So many improvements have been made that the Vanguard engine represents a new engine generation.

MAIN AREAS OF REDESIGN FOR SOLAR APPLICATION

- Heat system (receiver)
- Lubrication system
- Control systems
- Radiator systems

Fig 5. Areas of redesign

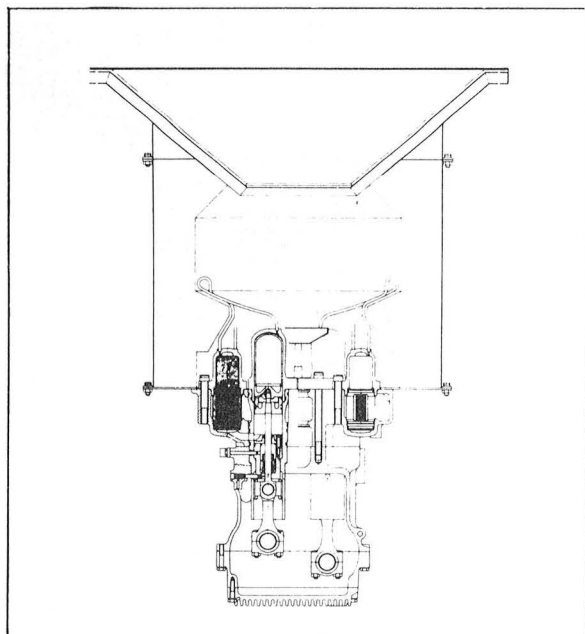


Fig 6. Vanguard engine cross section

Testing at United Stirling

A very vital part of the solar engine development has been engine testing. Six of United Stirling's 4-95 engines have been designated for development tests for the solar application. Fig 8 shows the main content of our development program. In addition during the last year tests have also been performed on JPL's engine, the 4-95 No 21 engine, located at Edwards Air Force Base. Five of United Stirling's engines have been tested in our laboratory in Malmö, Sweden. Two of these engines were used for component development tests, i.e. functional tests, usually of relatively short duration, of redesigned components and subsystems. Three of the engines were used for simulated solar cycle endurance tests. This test cycle, shown in fig 7, was based on loads and transients calculated from insolation statistics from Barstow and Albuquerque.

The lubrication system, the control system and the radiator system were first developed and tested on the engines in our laboratory.

A special engine stand was designed in order to turn the engines in the same way as in the actual concentrator. One of the engines was mowed out on our yard in order to gain experience from the outside environment. During the last three years 13000 hours of solar engine tests have been accumulated in Malmö.

After testing in our facilities all the subsystems have been on verification tests at Edwards Air Force Base, where the sixth of the 4-95 engines has been located.

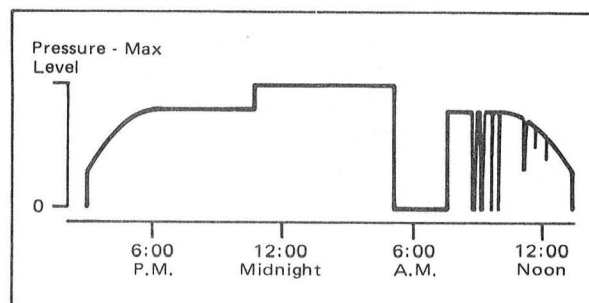


Fig 7. Simulated solar test cycle

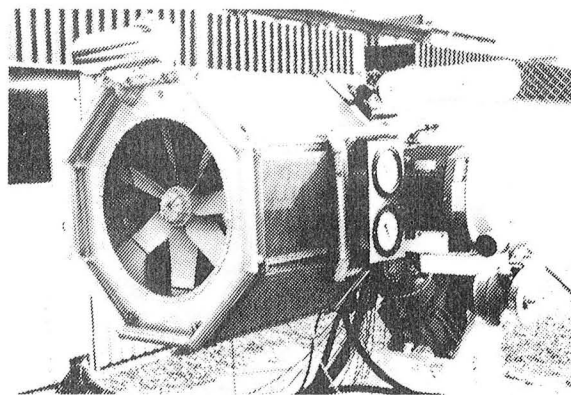


Fig 8. PCU on test stand

Actual solar tests

Testing of engines actually running on solar energy started 1981 at the test facility at Georgia Institute of Technology in Atlanta. This test facility is designed for higher power



than the 4-95 engine but testing was possible to perform by shielding the excessive flux with a watercooled plate. The testing in Atlanta gave very useful information for the further development of the receiver and control systems, but in order to evaluate the function of all components in a matched system there was still a need to test in a parabolic dish. Therefore the testing was transferred to JPL's test station at Edwards Air Force Base early in 1982 where testing has been going on since then jointly with JPL in their test bed concentrator.

Significant results evolving from these tests are among others the functions of the control systems during start, stop and cloud passages. The principal operation characteristics of the Vanguard PCU during these transients are shown in fig 11, 12 and 13.

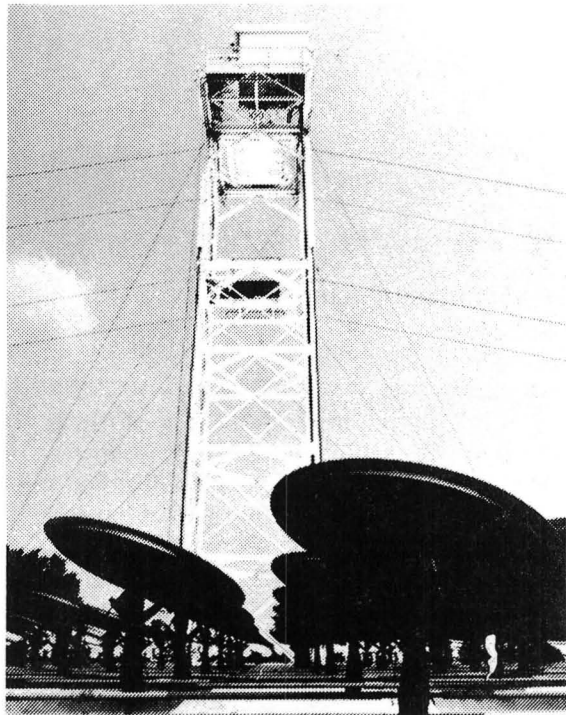


Fig 9. Tests in Atlanta

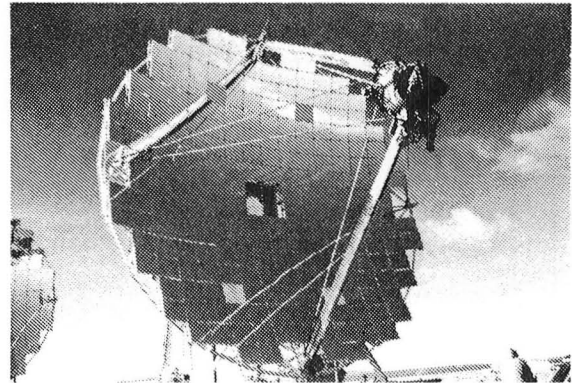


Fig 10. Tests at EAFB

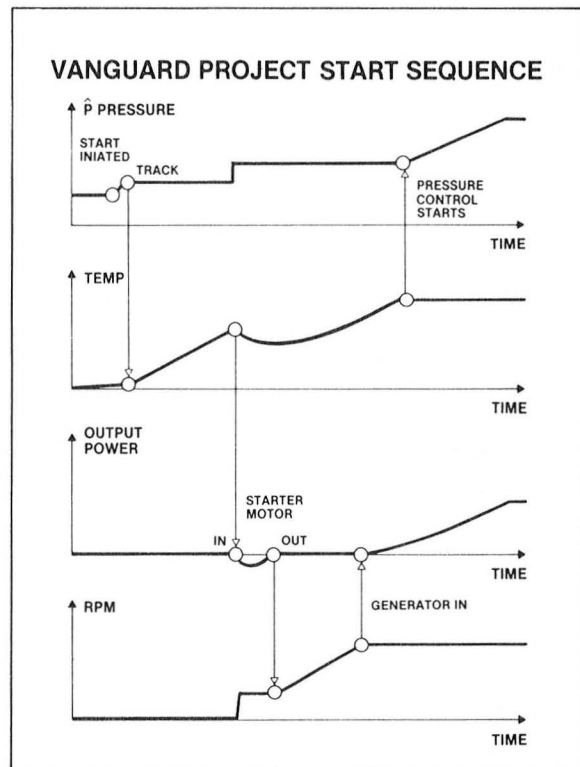


Fig 11. Start sequence

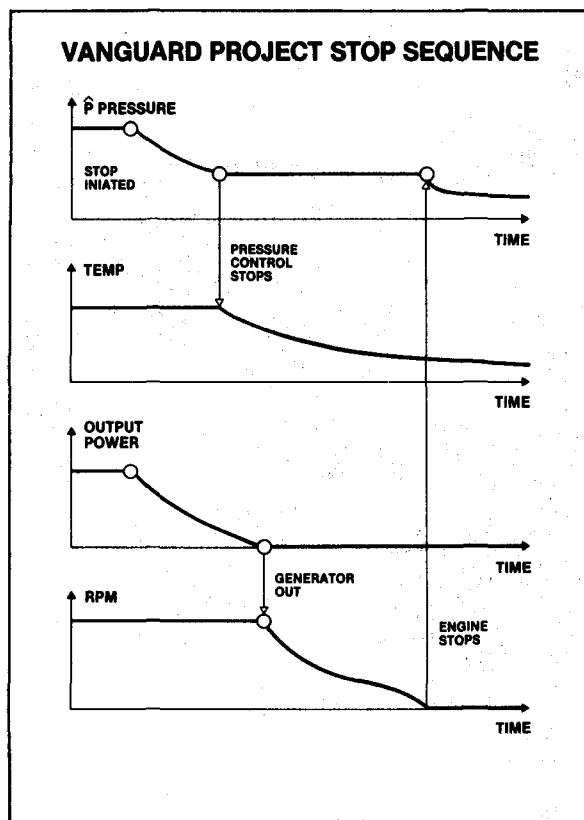


Fig 12. Stop sequence

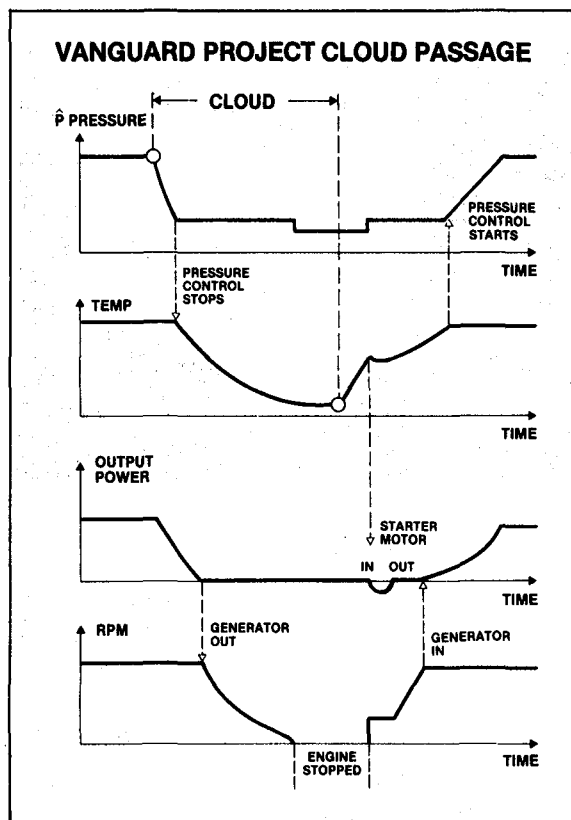


Fig 13. Cloud passage

4-95 Mk II (VANGUARD) ENGINE OBJECTIVES

- Keep Mk I performance level
- Increase reliability
- Reduce production cost

Fig 14. Vanguard engine objectives

The Vanguard project

United Stirling became member of the Vanguard project responsible for design and delivery of the power conversion unit. The contract was signed in May 1982. Our task in this project has included modification of the 4-95 engine in the earlier mentioned areas to fit together with the Advanco concentrators. The main objectives for the engine for this project are shown in fig 14. Laboratory tests have verified that the performance goals are met and calculations show a reduction of 30% in production costs. Several modifications of components aimed at increased reliability have been introduced. The results of these modifications can only be achieved thru future testing of the engine.

The PCU is now delivered to the test site and ready for testing.

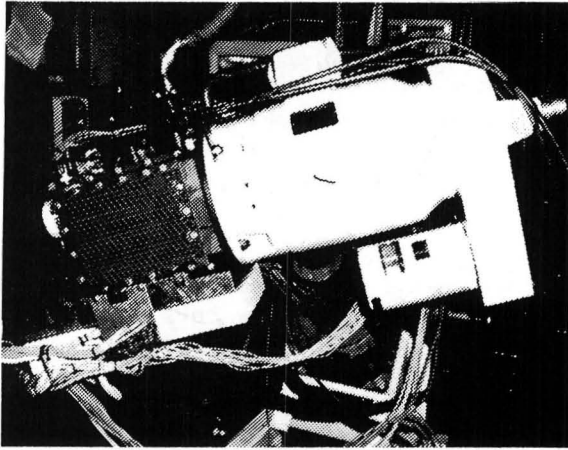


Fig 15. Laboratory testing of the Vanguard engine

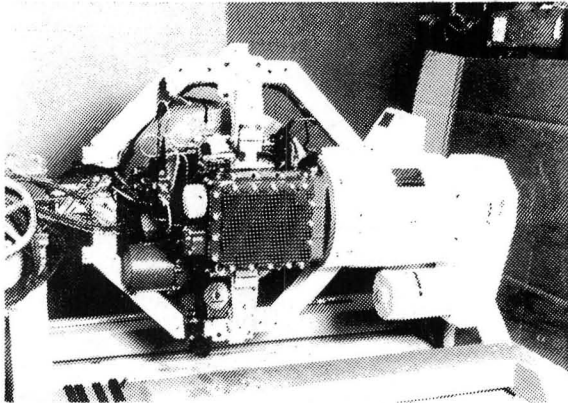


Fig 16. Vanguard engine with alternator and mounting ring

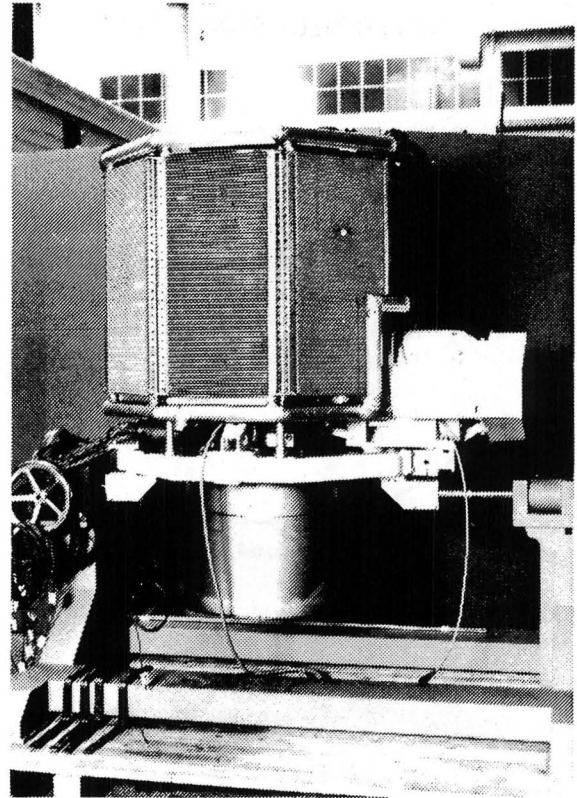


Fig 17. Vanguard PCU ready for delivery